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Modification of sugar profiles in California adapted apricots (*Prunus armeniaca* L.) through breeding with Central Asian germplasm

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Summary

Central Asian apricot germplasm was used in hybridizations with California adapted apricots to increase Brix levels and improve fresh eating quality. Fruit from parental trees, the F_1 hybrid and two backcross families were evaluated for fruit quality traits and analyzed by HPLC for specific sugar content. The F_1 hybrid between Central Asian and California adapted apricots was intermediate to its parents in many of the evaluated characteristics and levels of specific sugars. When the F_1 hybrid was backcrossed to California adapted apricots 'Lorna' and 'Robada,' the resulting hybrids were diverse in Brix, juice acidity, fruit size and profiles of specific sugars. Glucose: fructose ratios higher that 3.3 were encountered in fruit from five of the 22 analyzed seedlings, and fructose: sorbitol ratio ranged from 0.67 to 6.46. Brix and total sugar content correlated significantly with each other and with both sucrose and glucose. No significant correlations existed between sorbitol and any of the other analyzed sugars, nor with Brix or total sugars. The results demonstrated the extent of sugar profile modification possible in California adapted apricots after just two generations of breeding with Central Asian apricot germplasm.

Introduction

Consumers are willing to pay for high quality fruit but are also worried about the product quality they receive at retail outlets. Fruit quality is an abstract term that varies in meaning with different consumers. Flesh texture and firmness, visual appearance, flavor and aroma are all part of fruit quality as are levels of sweetness and acidity (Bruhn et al., 1991; Lockshin & Rhodus, 1991).

The Brix: acid (BA) ratio is a commonly used quality index in many types of fruit. Higher ratios are indicative of higher and more acceptable fruit quality. The BA ratio is commonly calculated from representative fruit juice samples using refractometer readings and titrations. As fruit matures, sugar levels rise and juice acidity decreases, leading to higher BA ratios in fruit of more advanced maturity (Gómez & Ledbetter, 1997). While BA ratios provide a rough fruit quality index, they do not yield any information about the levels of specific acids and sugars present in the fruit tissue.

Sucrose is generally accepted as the predominant sugar present in apricot fruit. Other sugars such as glucose, fructose, maltose, sorbitol and raffinose are also present at varying lesser concentrations (Witherspoon & Jackson, 1995). The collective concentrations of the sugars present in a given fruit are known as a sugar profile. Sugar profiles remain generally stable within a given apricot accession even though the absolute values of the present sugars will change from year to year (Bassi et al., 1996). The sugar profile and ratios of specific sugars are useful tools in authenticization of juice samples. After surveying 11 Italian apricot varieties, Impembo et al. (1995) reported an average glucose: fructose ratio of 2.3 and range from 1.6 to 3.1 for the varieties. A glucose: fructose ratio over 3.3 indicated to

these researchers that the apricot juice sample had been adulterated and that glucose was added to either mask juice acidity or to return the glucose: fructose ratio to the baseline 2.3 value.

In the field of human nutrition there is a growing interest in fruits that are rich in sorbitol for special dietary purposes. Sorbitol can be used as a glucose substitute for diabetics and as an alternative natural sweetener for sucrose (Forni et al., 1992). Sorbitol is considered one of the minor sugars present in apricot fruit. While fresh pears contain levels of 1.2% to 2.8% sorbitol on a fresh weight basis (Wrolstad & Shallenberger, 1981), much lower levels are reported present in fresh apricots. Impembo et al. (1995) reported sorbitol levels to range from 0.2% to 0.5% FW in 11 Italian apricot varieties. Sorbitol levels ranged from 0.28% to 0.32% for fresh 'Patterson' apricots from immature to mature fruit (Ledbetter et al., 2002). Fruit breeders are also finding specific interest in sorbitol rich fruits. Sorbitol has a positive effect on browning during fruit drying since it does not participate in Malliard reactions associated with the drying process. Sorbitol also acts as a humectant in keeping dry products softer and more pliable. As such it acts as a natural preservative to keep dry fruit quality high during storage. These positive attributes of sorbitol can be offset by the negative side effects of its excessive use as a sugar substitute. Natural products rich in sorbitol or sorbitol-modified products have induced both decreased carbohydrate absorption and gastrointestinal problems (Nobigrot et al., 1997; Wang & van-Eys, 1981).

Apricot breeding efforts at Agricultural Research Service's Parlier, CA location are directed at improving both fresh and dry fruit quality. Central Asian apricot germplasm from northern Pakistan (Hunza region) has been used for a number of years in hybridizations with our California adapted apricots to increase Brix and thereby improve eating quality. These Hunza apricots are also world renowned for their exceptionally fast drying ability and dry product quality. However, they are not well adapted to California's climate and fruit production is very poor from Hunza trees grown in California orchards. Furthermore, fruit size of the Hunza germplasm is far too small for California's growers and consumers. F_1 hybrids between California adapted and Hunza apricots are quite productive, and Brix levels are somewhat elevated; however, fruit size is still a detrimental factor among F_1 trees. In this study, we provide results of backcrossing a specific F_1 hybrid to California adapted apricots with emphasis on sugar profiles in the resultant hybrids.

Materials and methods

Plant materials

Central Asian apricot germplasm was secured as open-pollinated seedlots from known mother trees in the Hunza region of northern Pakistan (Thompson, 1998). In this study, apricot accession '1394-1' was used as the sole source of Central Asian germplasm. 1394-1 is an open-pollinated seedling from the clonal accession 'Burum Gakas,' (Ledbetter & Peterson, 2004) and was grown in a flood irrigated orchard at the ARS San Joaquin Valley Agricultural Sciences Center in Parlier, California.

Hybridizations to produce first and second generation seedling populations were accomplished using traditional tree fruit breeding techniques (Layne, 1983). In 1994 accession 1394-1 was hybridized with the California adapted apricot variety 'Nicole.' A hybrid from this cross, Y102-51, was selected from among 12 siblings for future breeding efforts because of its productivity, fruit size, and aromatic fruit quality. In 1998 accession Y102-51 was hybridized with California adapted apricots 'Lorna' and 'Robada.' These crosses were performed in an attempt to select larger fruited apricots with similar Brix and BA ratios as compared to 1394-1. Fourteen seedling trees were planted to the field in the spring of 1999 from the Y102-51 X Lorna cross, and 24 trees were planted at the same time for the Y102-51 X Robada cross. By 2002, the first year that these progenies were able to fruit, field attrition had reduced family sizes to 10 trees in the Y102-51 X Lorna progeny and 18 trees in the Y102-51 X Robada progeny. Some of these remaining trees in each progeny failed to fruit during the time of this study.

All first and second generation seedling trees reported in this study were grown on their own root in a single orchard block, and replicates or clones of these trees were non-existent. Cultivar development was the primary purpose of producing these hybrids, and as such, seedling trees were planted out in progeny rows, with approximately 50 cm separating trees within the row. These progenies were planted randomly in the orchard block along with many other apricot progenies as row space and existing trees permitted placement. The California adapted apricot accessions used in hybridizations ('Nicole,' 'Lorna' and 'Robada'), as well as 1394-1, were propagated and grown on 'Nemaguard' seedling peach rootstock in the same orchard block. Cultural practices conducive to quality fruit

production were performed on all the trees used in this study.

Fruit evaluations

Fruit were thinned to commercial crop levels approximately one month after the bloom period to ensure that adequate photosynthate would reach all fruit and ensure maximum growth potential. Harvest was accomplished at a commercial level of fruit maturity. Fruit reported on herein had firmness readings of between 3 kg to 4 kg when subjected to a fruit penetrometer equipped with an 8 mm blunt tip. However, the original 1394-1 and several of the resulting hybrids had fruit too small for firmness evaluation. Organoleptic sampling of these fruits indicated when their commercial level of maturity had been attained.

Seven to ten fruit from each apricot accession were used for fruit quality evaluations. Brix, titratable acidity and pH were obtained from composite juice samples that were derived from longitudinal slices of each sampled fruit. Three independent juice samples were obtained for each apricot accession to determine Brix, acidity and juice pH. Five grams of juice were diluted with 50 ml distilled water for titratable acidity and juice pH determination. Titrations were run to pH 8.1 with 0.1 M NaOH. Data presented in this study were tabulated with the statistical package SYSTAT 8.0 (Chicago, IL).

Sugar profile evaluations

As apricot accessions matured and were evaluated, additional fruit were harvested and frozen for sugar analysis at the end of the fruit maturity period. For sugar profile analysis, the equatorial areas of individual fruit were punched with a sharp No. 3 cork borer. Three or four bores from separate fruit were then subsampled to provide working samples of 0.3 g to 0.5 g fresh weight. Three samples were analyzed per apricot accession. Flesh samples were then placed in plastic scintillation vials along with 2 ml of 80% EtOH. The vials were placed in an 80°C water bath for 1 h. After this extraction, the ethanolic supernatant was decanted and brought back to 2.0 ml with 80% EtOH. The fruit tissues were then discarded and the ethanolic extract was transferred back onto the scintillation vials.

The vials were then placed in a Labconco 4322000 vortex evaporator set at 55°C and run for approximately 40 min. or until the alcohol had evaporated. Residues were re-hydrated with 1.0 ml HPLC grade water and the vials agitated every 15 min. for 1 h. The aqueous sugar solutions were then transferred to 12 × 32 mm clear autosample vials with TFE/silicon caps after passing the liquid through a 0.2 μm nylon HPLC syringe filter.

A Hewlett-Packard Series 1050 HPLC instrument equipped with a series 1050 Automatic Sampler, a Waters Model 410 differential Refractometer and a Shimadzu Chromatopac integrator Model C-R8A was used for analysis. Injection volume of extract was 20 μl. The soluble sugars in the samples were separated using a 300 mm × 6.5 mm Altec 700CH carbohydrate column heated to a constant 80°C with a Jones chromatography column oven (Lakewood, CO 80228). Solvent was HPLC grade water at a flow rate of 0.5 ml min^{-1}.

Results

Fruit evaluation indices and sugar profile information for parents 1394-1 and 'Nicole,' as well as the resultant F_1 hybrid Y102-51, are presented in Table 1. An exceptionally high level of sorbitol was encountered in parent 1394-1 as compared with sorbitol levels published previously for fresh apricot fruit (Impembo et al., 1995; Ledbetter et al., 2002). Sorbitol and raffinose are generally considered to be minor sugars in apricot fruit. However, the sorbitol present in 1394-1 is over two times its level of fructose (Table 1). Accession 1394-1 had high Brix (23.0) and low acidity (0.46%) that led to an exceptionally high BA ratio (50.0). Higher BA ratios have correlated well in other fruit crops with higher eating quality (Abbott et al., 2004; Flora, 1979; Guyer et al., 1993; Harker et al., 2002). The hybrid Y102-51 generally exhibited intermediate values for the various characteristics presented in Table 1 as compared to parents 1394-1 and 'Nicole.' However, the level of sucrose encountered in fruit of Y102-51 was approximately 20% higher than either parent. Brix levels in both 2002 and 2003 were lower in Y102-51 than in the pollen parent 'Nicole.' While Y102-51's Brix level was lower than that of 'Nicole,' the BA ratio of Y102-51 (31.8 in 2002, 27.9 in 2003) was intermediate to 'Nicole' (20.6 in 2002, 22.5 in 2003) and 1394-1 (50.0 in 2004).

Seedlings in the backcross progenies began to fruit in 2002 and fruit evaluation data were collected the first two years of fruiting (Table 2). Apricot accessions with fruit larger than Y102-51 were identified in both progenies. In the Y102-51 X Lorna progeny, average fruit weight in the family was 50.9 g in 2002 (range = 37.7 g to 61.2 g) and 58.9 g in 2003 (range = 45.7 g to 70.1 g). Family average fresh fruit weight was very similar for

Table 1. Levels of individual sugars (average ± standard deviation in mg g^{-1}), sugar ratios and fresh fruit evaluation data for Hunza apricot accession 1394-1, California adapted apricot variety 'Nicole' and their resulting hybrid, Y102-51

Generation	Raffinose	Sucrose	Glucose	Fructose	Sorbitol
Parentals					
1394-1	0.17 ± 0.02[a]	51.74 ± 6.60	36.03 ± 3.07	12.00 ± 1.70	29.42 ± 4.08
Nicole	0.71 ± 0.01	50.00 ± 2.86	25.46 ± 0.93	10.72 ± 0.63	4.53 ± 0.44
F_1 (1394-1 X Nicole)					
Y102-51	0.36 ± 0.11	61.57 ± 4.61	30.72 ± 2.23	11.11 ± 1.05	10.18 ± 0.23

Accession	Total sugars	Total sugars: Sorbitol	Glucose: Fructose	Fructose: Sorbitol
1394-1	129.36	4.39	3.00	0.41
Nicole	91.42	20.18	2.37	2.37
Y102-51	113.94	11.19	2.76	1.09

	Fruit wt. (g)		Brix		Acidity (%)		Juice pH	
Accession	2002	2003	2002	2003	2002	2003	2002	2003
1394-1[b]	9.4		23.0		0.46		4.40	
Nicole	58.5	76.5	19.6	17.3	0.95	0.77	3.45	3.50
Y102-51	39.9	54.6	17.5	14.8	0.55	0.53	3.71	3.76

[a]Values presented for raffinose, sucrose, glucose, fructose and sorbitol represent an average ± standard deviation of three independent fruit samples extracted and analyzed at commercial maturity.
[b]Fruit from accession 1394-1 was only available during the 2004 season.

Table 2. Two-year fruit evaluation characters for Lorna, Robada and progenies arising from hybridizations of these two California adapted apricots with Y102-51

Evaluated character	Lorna	Y102-51 X Lorna progeny[a]	Robada	Y102-51 X Robada progeny[b]
Fruti wt. (g)				
2002	110.0	37.7–61.2	105.3	32.2–90.1
2003	134.0	45.7–70.1	128.2	43.1–82.5
Brix				
2002	15.3	16.3–19.5	16.4	13.1–21.1
2003	15.4	13.4–16.5	15.8	13.2–18.4
Acidity (%)				
2002	1.01	0.75–0.89	0.74	0.41–0.92
2003	1.07	0.58–1.17	0.80	0.32–0.88
Juice pH				
2002	3.26	3.34–3.77	3.32	3.39–4.17
2003	3.16	3.27–3.78	3.41	3.30–4.16
Brix: Acid ratio				
2002	15.1	19.4–26.0	22.1	19.0–49.1
2003	14.4	14.1–27.2	19.7	14.7–43.8

Ranges presented in progeny columns represent all trees that fruited in a given year.
[a]Value ranges listed for the Y102-51 X Lorna progeny represent four fruiting trees in 2002, and five fruiting trees in 2003.
[b]Value ranges listed for the Y102-51 X Robada progeny represent 14 fruiting trees in 2002, and 16 fruiting trees in 2003.

Y102-51 X Robada trees with average weights of 50.1 g and 58.6 g in 2002 and 2003, respectively. These family average fresh fruit weights were intermediate between Y102-51 (39.9 g in 2002, 54.6 g in 2003) and pollen parents 'Lorna' (110.0 g in 2002, 134.4 g in 2003) or 'Robada' (105.3 g in 2002, 128.2 g in 2003). While no seedlings from either progeny produced fruit as large as either 'Lorna' or 'Robada,' seedlings having fruit of acceptable commercial size (i.e. 60 g) were identified in each family.

Elevated Brix levels were observed in fruit from some of the seedlings in both progenies. Brix level averages of each family were very similar for each harvest year. Fruiting trees in the family Y102-51 × Lorna had average Brix levels of 17.8 (range = 16.3 to 19.5) and 15.3 (range = 13.4 to 16.5) in harvest years 2002 and 2003, respectively. Brix levels of fruiting trees from the Y102-51 X Robada family averaged 17.6 (range = 13.1 to 21.1) in 2002 and 15.4 (range = 13.2 to 18.4) in 2003. Juice acidity was markedly higher in the Y102-51 × Lorna family as compared with Y102-51's family with 'Robada.' This would seem to be a result of higher juice acidity for 'Lorna' as compared with 'Robada' (Table 2). Average juice acidities from fruiting trees in the Y102-51 × Lorna progeny were 0.81%

and 0.78% in 2002 and 2003, respectively. Juice acidities were lower for the Y102-51 × Robada progeny with averages of 0.61% and 0.59% in 2002 and 2003, respectively. The lower juice acidity and increased Brix values observed among specific fruiting trees in these progenies provided for very acceptable BA ratios. BA ratio averages for each progeny in both harvest years were substantially higher than either California adapted pollen parent. In the Y102-51 × Lorna progeny, BA ratio averages of 22.1 (range = 19.4 to 26.0) and 20.7 (range = 14.1 to 27.2) were recorded in 2002 and 2003, respectively, compared to the BA ratio of 'Lorna' being 15.1 in 2002 and 14.4 in 2003. Similarly, BA ratio averages of 30.4 (range = 19.0 to 49.1) and 28.9 (range = 14.7 to 43.8) were recorded in 2002 and 2003, respectively for fruiting trees in the Y102-51 × Robada progeny. The calculated BA ratio of 'Robada' was 22.1 and 19.7 in 2002 and 2003, respectively. In the Y102-51 × Lorna progeny, only accession Y103-120 in 2003 had a BA ratio lower than that of 'Lorna' (14.1 vs. 14.4), but none of the seedlings in the progeny had a BA ratio as high as that of Y102-51 (data not presented). Eleven of the 14 fruiting seedling trees from the progeny Y102-51 × Robada had higher BA ratios than 'Robada' in 2002, and 14 out of 16 fruiting trees had higher BA ratios than 'Robada' in 2003. Five trees in this progeny bettered Y102-51's BA ratio in 2002 and eight trees had higher BA ratios than Y102-51 in 2003.

Large differences in sugar profiles and ratios between specific sugars were observed in each of the progenies. Sucrose and glucose were the most prevalent sugars in fruit of all seedlings from each progeny. Raffinose was always the sugar of least concentration, and maximum raffinose levels of 0.98 mg g^{-1} were realized in fruit from seedling tree Y103-118 (Y102-51 × Lorna family). Total combined sugars were almost equal on a family basis with the Y102-51 × Lorna family averaging 97.45 mg g^{-1} and Y102-51 × Robada averaging 101.88 mg g^{-1}. Fructose and sorbitol levels differed markedly in each of the seedlings from both families. Even though parental apricots differed widely in glucose: fructose ratio (4.60 vs. 3.30 for 'Lorna' and 'Robada,' respectively), family averages were very similar for this important variable (3.11 for Y102-51 × Lorna and 3.05 for Y102-51 × Robada). While there were no seedlings observed having fruit with a glucose: fructose ratio higher than 4.0, five seedlings did have glucose: fructose ratios higher than 3.30. The fructose: sorbitol ratio ranged from 0.67 to 6.46 in the Y102-51 × Lorna family and from 0.68 to 3.46 for Y102-51 × Robada (Table 3).

Numerous significant correlations were encountered between various sugar variables and ratios of specific sugars (Table 4). Total sugars had a highly significant correlations with both glucose ($r = 0.896$) and fructose ($r = 0.738$). The correlation between Brix and total sugars was highly significant ($r = 0.817$). Sorbitol did not correlate significantly with either fructose ($r = 0.534$) or glucose: fructose ratio ($r = -0.396$). Fructose: sorbitol ratio had very low correlation values for all individual sugars except sorbitol, which was highly significant ($r = -0.811$).

Discussion

While consumers cherish the beauty and aromatic flavor of high quality apricots, complaints are sometimes frequent at the retail level where sub-optimal fruit quality can dominate the marketplace. A lack of sugar or sweetness in purchased apricot fruit is among the most common consumer complaint (Moreau-Rio & Roty, 1998). To address this issue, breeding efforts have been undertaken to increase Brix in California adapted apricots through the use of apricot germplasm from the Hunza region of Pakistan. Apricots from this region are representative of the Central Asian eco-geographical group and are characterized generally as being long-lived, vigorous trees having late bloom. Apricots of this group are typically small-fruited and have excellent drying characteristics (Faust et al., 1998). By themselves, the Hunza apricot germplasm is ill-adapted and generally not useful in California growing conditions. Hunza trees growing in California's central valley do bloom a full month after the typical apricot bloom period and fruit set on these trees is sparse at best. None of the imported Hunza germplasm has produced fruit of more than 40 g. This is below the minimum weight necessary for fresh market apricots in California and United States markets.

Recent suggestions have been made to utilize wild or exotic *Prunus* germplasm in breeding programs to introduce novel traits or improve general fruit quality (Hagen et al., 2002; Wu et al., 2003). The introgression of Central Asian *P. armeniaca* L. germplasm into our California adapted apricots began with the importation of numerous clonal apricots and seedlots from the Hunza region of Pakistan in 1988. While none of the Hunza clonal apricots survived during quarantine, seedlots from the clonal trees were distributed to interested *Prunus* breeding programs throughout the United States (Thompson, 1998). Fruit was first observed on

Table 3. Levels of individual sugars (average ± standard deviation in mg g^{-1}), and sugar ratios in fresh apricot fruit from progenies of Y102-51 hybridized with either 'Lorna' or 'Robada' apricots

Accession	Raffinose	Sucrose	Glucose	Fructose	Sorbitol
Lorna	0.49 ± 0.05	67.19 ± 4.41	27.62 ± 1.88	6.00 ± 0.83	3.20 ± 2.75
Y102-51 × Lorna progeny					
Y103-117	0.82 ± 0.07	59.89 ± 2.61	29.76 ± 0.83	10.15 ± 0.39	14.27 ± 0.89
Y103-118	0.98 ± 0.02	59.50 ± 7.09	28.91 ± 2.87	9.52 ± 0.94	14.28 ± 1.13
Y103-120	0.12 ± 0.22	59.35 ± 2.27	27.20 ± 0.82	8.37 ± 0.21	6.25 ± 1.30
Y103-121	0.50 ± 0.04	52.53 ± 2.94	27.51 ± 1.58	9.04 ± 0.53	1.40 ± 0.20
Y103-122	0.08 ± 0.07	45.19 ± 3.45	24.17 ± 1.13	7.20 ± 0.20	1.17 ± 0.20
Y103-124	0.39 ± 0.06	50.19 ± 4.03	25.90 ± 2.40	8.50 ± 1.03	1.59 ± 0.31
Robada	0.34 ± 0.09	61.61 ± 4.49	30.45 ± 1.80	9.24 ± 1.11	3.57 ± 0.49
Y102-51 × Robada progeny					
Y103-204	0.34 ± 0.04	36.16 ± 3.75	21.71 ± 1.66	7.04 + 0.62	6.87 ± 1.08
Y103-206	0.08 ± 0.13	60.35 ± 3.87	33.90 ± 1.96	12.08 ± 0.22	3.49 ± 0.33
Y103-207	0.47 ± 0.08	47.17 ± 6.74	25.98 + 2.83	6.56 ± 0.82	4.00 ± 0.63
Y103-208	0.47 ± 0.01	40.41 ± 2.07	23.11 ± 2.02	7.98 ± 0.86	10.75 ± 2.37
Y103-209	0.17 ± 0.02	42.40 ± 5.34	26.36 ± 3.47	8.13 ± 1.11	11.07 ± 1.70
Y103-210	0.30 ± 0.09	55.84 ± 7.42	36.99 + 4.18	14.32 ± 1.16	13.29 ± 0.75
Y103-211	0.59 ± 0.14	45.53 ± 7.36	32.39 ± 5.11	13.44 ± 2.18	16.34 ± 2.39
Y103-212	0.05+0.08	41.92 ± 2.59	23.91 ± 1.56	8.95 + 0.61	11.75 ± 1.43
Y103-215	0.05 ± 0.08	55.31 ± 2.46	30.52 ± 2.46	10.19 ± 0.94	8.67 ± 0.64
Y103-217	0.51 ± 0.44	57.57 ± 9.83	41.49 ± 7.85	13.00 ± 2.55	11.48 ± 1.90
Y103-218	0.00 ± 0.00	54.67 ± 3.15	31.20 ± 1.48	10.21 ± 0.60	14.35 ± 2.85
Y103-222	6.17 ± 0.04	49.28 ± 3.17	31.29 ± 1.38	8.84 ± 0.42	7.14 ± 1.36
Y103-226	0.06 ± 0.10	42.43 ± 4.51	31.43 ± 4.64	10.13 ± 1.74	9.40 ± 1.84
Y103-228	0.19 ± 0.06	51.70 ± 4.47	35.32 ± 4.33	9.79 ± 1.54	14.37 ± 2.75
Y103-229	0.14 ± 0.14	38.60 ± 3.92	34.92 ± 3.58	15.54 ± 1.84	14.10 ± 1.05
Y103-230	0.22 ± 0.05	67.34 ± 5.24	42.52 ± 1.20	12.45 ± 0.34	10.87 ± 1.53

Accession	Total sugars	Total sugars: Sorbitol	Glucose: Fructose	Fructose: Sorbitol
Lorna	104.50	32.66	4.60	1.88
Y102-51 × Lorna progeny				
Y103-117	114.90	8.05	2.93	0.71
Y103-118	113.19	7.93	3.04	0.67
Y103-120	101.29	16.21	3.25	1.34
Y103-121	90.98	64.98	3.04	6.46
Y103-122	77.81	66.50	3.36	6.15
Y103-124	86.57	54.45	3.05	5.35
Robada	105.21	29.47	3.30	2.59
Y102-51 × Robada progeny				
Y103-204	72.12	10.50	3.08	1.02
Y103-206	109.90	31.49	2.81	3.46
Y103-207	84.18	21.05	3.96	1.64
Y103-208	82.72	7.69	2.90	0.74
Y103-209	88.13	7.96	3.24	0.73
Y103-210	120.74	9.09	2.58	1.08
Y103-211	108.29	6.63	2.41	0.82
Y103-212	86.58	7.37	2.67	0.76
Y103-215	104.74	12.08	3.00	1.18
Y103-217	124.05	10.81	3.19	1.13
Y103-218	110.43	7.70	3.06	0.71
Y103-222	96.72	13.55	3.54	1.24
Y103-226	93.45	9.94	3.10	1.08
Y103-228	111.37	7.75	3.61	0.68
Y103-229	103.30	7.33	2.25	1.10
Y103-230	133.40	12.27	3.42	1.15

Values presented for individual sugars are representative of three independent fruit samples extracted and analyzed at commercial maturity.

Table 4. Correlation matrix for Brix, individual sugars, specific sugar ratios and total sugar content among 2004 fruiting seedlings of Y102-51 × Lorna and Y102-51 × Robada apricot families

	Brix	Sucrose	Glucose	Fructose	Raffinose	Sorbitol	Glu: Fru	Fru: Sorb
Sucrose	0.662*,[a]							
Glucose	0.744**	0.579						
Fructose	0.558	0.278	0.805**					
Raffinose	0.159	0.199	−0.042	−0.007				
Sorbitol	0.419	0.045	0.409	0.534	0.215			
Glu: Fru	0.022	0.191	−0.075	−0.629	−0.051	−0.396		
Fru: Sorb	0.253	0.024	−0.250	−0.245	−0.057	−0.811**	0.095	
Tot. Sugars[b]	0.817**	0.784**	0.896**	0.738**	0.169	0.548	−0.141	−0.353

[a]* and ** represent statistical significance at the 0.05 and 0.01 levels, respectively.
[b]Tot. Sugars = sucrose + glucose + fructose + raffinose + sorbitol.

some of the seedling Hunza trees during 1993 in the central San Joaquin Valley of California and speculative hybridizations began during the 1994 bloom period.

Progenies utilized in the current study consisted of only small numbers of seedling trees, but the results successfully demonstrated the variability in sugar profile components that can be generated after just two generations of breeding. This current study highlights the results of only a single desired breeding objective through incorporation of Hunza apricot germplasm into the California adapted apricots. Other valuable horticultural traits exist in the Hunza apricot germplasm, and numerous other hybrid progenies exist that were created to exploit those novel characteristics. Besides hybrid progenies created with 'Burum Gakas,' F_1 progenies have been created between specific California adapted apricots and 17 different Hunza apricot parents. To date, nearly 700 F_1 hybrids have been created to incorporate the distinct and novel characteristics of the Hunza apricots into our California adapted apricot breeding program (Ledbetter and Peterson, 2004). Phenotypic variability is now being evaluated in the oldest F_2 and backcross populations, and hybridizations are being performed among elite large-fruited high Brix individuals to further concentrate these traits of interest in apricots adapted to the California environment. New and distinct sugar profiles are evident among the seedling trees analyzed in this current study. Future studies of these new apricots should involve consumer taste panels, postharvest performance and productivity trials to determine whether or not variety introduction is warranted.

The incorporation of Central Asian germplasm into California adapted apricots through traditional hybridization has had a dramatic effect on the sugar profiles of the resulting hybrids. Levels of the five analyzed soluble sugars in some of the hybrids differed greatly from published levels of sugars in other apricot germplasm. The 4.60 glucose: fructose ratio encountered in 'Lorna' fruit was extremely high by other published accounts, and added to the variability in resulting sugar profiles of seedlings derived from it. Previous work suggested that glucose: fructose ratios greater than 3.30 in fresh apricot fruit were indicative of sample adulteration (Impembo et al., 1995). In this study, 5 of the 22 seedlings from the combined 'backcross' families had authentic glucose: fructose ratios in excess of 3.30. At the same time, a highly significant correlation ($r = 0.805$) existed between glucose and fructose levels in fruit from the combined seedling families. Genetic loci that control the partitioning of glucose and fructose without effecting total sugars or Brix have recently been identified from planned interspecific hybridizations within *Lycopersicon* (Levin et al., 2000). Levels of fruit sucrose and glucose in Y102-51's families with 'Lorna' and 'Robada' differed from what would have been expected. Family averages of sucrose content for both families were much lower than would have been expected given the sucrose levels present in parents. Fruit glucose level from the Y102-51 × Lorna family was only slightly below that of the lowest parent 'Lorna' (27.62 mg g^{-1} vs. 27.24 mg g^{-1}), while in the Y102-51 × Robada family, fruit glucose surpassed the level present in both parents (31.44 mg g^{-1} vs. 30.72 mg g^{-1} and 30.45 mg g^{-1} for Y102-51 and 'Robada,' respectively).

Large differences in sorbitol levels were also encountered in the apricot progenies. While no seedling in either progeny had sorbitol levels approaching that of fruit from 1394-1, seedlings were found in each of the progenies with fruit having sorbitol levels at levels

nearly 1.5 times that of the sorbitol level in parent Y102-51. Furthermore, sorbitol levels were actually higher in concentration than fructose levels in some of the seedlings. Fructose: sorbitol ratio was less than 1.0 in two of the six seedlings from the Y102-51 × Lorna progeny and in six of the 16 seedlings from Y102-51 × Robada. The selection and utilization of sorbitol-rich apricots for drying could be a positive step in breeding as sorbitol does not undergo Maillard reactions (Wilford et al., 1997), and improved dry fruit quality could result from reduced product discoloration. The humectant property of sorbitol has also been shown to positively influence product quality (Chen et al., 2000; Erba et al., 1994).

Several studies have previously characterized *Prunus* populations or clonal collections for patterns of variation in sugar and organic acid contents (Bassi et al., 1996; Dirlewanger et al., 1999; Gurrieri et al., 2001; Wu et al., 2003). These studies are in general agreement that the growth environment influences levels of specific sugars and fruit acids, but that the profile of those sugars and acids is relatively constant across environments. Bassi et al. (1996) suggested that seedlings could be selected according to their specific phenotype (i.e. sugar profile component) with reasonable confidence using only data for a single harvest season. Heritability estimates of specific sugars in apricot fruit based on progeny and mid-parent means ranged from a low of 0.44 for sucrose to a high of 0.58 for fructose. Total sugar heritability was estimated at 0.62, while a specific h^2 value for sorbitol was not given (Bassi et al., 1996). In other studies Brix was shown to be highly correlated with sucrose, and total sugars correlated with sucrose levels as well (Dirlewanger et al., 1999; Gurrieri et al., 2001). Significant correlations were also observed between glucose and fructose (Dirlewanger et al., 1999; Wu et al., 2003), as was the case in the present study. Our present results verify other studies in demonstrating significant phenotypic correlations of Brix with both sucrose and total sugar level; however, no significant correlations existed in the present study between sorbitol and any of the other specific sugars, nor with Brix or total sugars. Thus, it appears that sorbitol content assorts independently with regard to other specific sugars in fresh apricot, and breeders could exploit this fact to identify new hybrids with novel sugar profiles. Given that progeny sizes are sufficiently large, and that the necessary variability in sorbitol content existed in parents of the original hybridizations, F_2 hybrids with either low or high sorbitol content could be identified in trees having fruit with either high or low total sugar content.

The use of biochemical analyses can benefit an apricot breeding program by identifying accessions with specific sugar profiles of particular interest. Identifying low glucose: fructose ratio individuals might be of particular interest as fructose has a high level of perceived sweetness (Pangborn, 1963). Our current study demonstrates the diverse and independent segregations of specific sugars when hybridizations are performed between apricots having dramatically different sugar profiles. Further, our results show the extent of sugar profile modification possible in California adapted apricots after just two generations of breeding with Central Asian apricot germplasm.

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